REMARKS

Applicants respectfully request amendment to the instant application under 37 C.F.R. 1.312 to include correction of a minor error relating to units therein. Specifically, the unit for sheet resistance is changed to "Ω/square" which is well known in the art. To support this knowledge, Applicants provide herewith an excerpt from a textbook "Semiconductor Devices" for the Examiner's consideration.

Entry, therefore, is believed to be fully appropriate under 37 C.F.R. §1.312 since no new matter is added by this amendment.

In the event that the Examiner has any questions relating to this Amendment or to the application in general, it would be appreciated if the Examiner would telephone the undersigned attorney concerning such questions so that prosecution of this application may be expedited.

In view of the above, entry of the same prior to issuance is respectfully requested.

Respectfully submitted,

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SEMICONDUCTOR DEVICES

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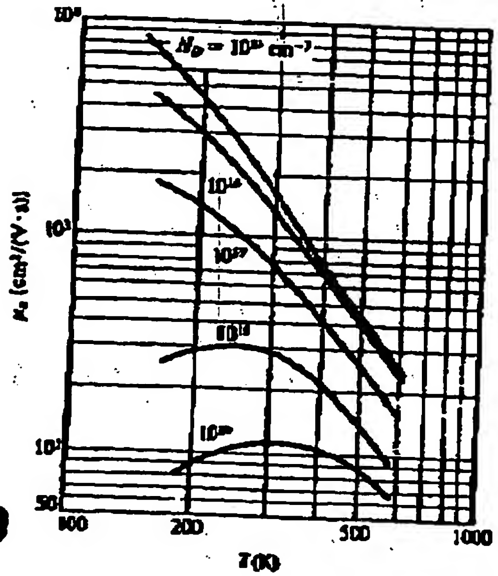

FIGURE 4.2.6
Electron mobility in N-type Si vs. temperature for several doping concentrations [9].

temperatures, collisions with impurity ions are the prevalent mechanism and the graph rises with $T^{3/2}$. At high temperature, intrinsic, neutral atom collisions become the determining mechanism and the mobility drops with increasing temperatures, following a $T^{-3/2}$ curve. In between there is a transition range of temperatures, where the graph reaches a maximum before beginning to decay.

A more comprehensive picture of the phenomenon is given by the empirical graph of Fig. 4.2.6 [9], in which each curve of constant doping is seen to follow roughly the shape of Fig. 4.2.5. Notice that, as expected, with increasing dopant concentrations, the position of the maximum is displaced toward higher and higher temperature ranges.

Example 4.2.2. The same specimen as in Example 4.2.1 is brought to a temperature of 500 K. Compute the resistance and comment on the relative contribution of the electrons and holes to conduction.

Solution. From Fig. 4.2.6, interpolating for $N = 1.9 \times 10^{17}$ cm^{-3} and $T = 500$ K:

$$\mu_n \approx 220 \text{ cm}^2/(\text{V}\cdot\text{s})$$

The intrinsic concentration is computed from (3.3.7):

$$n_i = 3.65 \times 10^{14}$$

This is two orders of magnitude less than N_D, so the approximation of (3.3.13) holds and the minority carrier concentration is

$$p_n = \frac{(3.61 \times 10^{14})^2}{10^{16}} = 1.3 \times 10^{13} \text{ cm}^{-3}$$

as this quantity is still 3 orders of magnitude smaller than the majority carrier concentration, the contribution of the holes to conduction is negligible, and the conductivity can be computed on the basis of the electrons only:

$$\sigma \approx 1.6 \times 10^{-19}(220 \times 10^{16}) = 0.35 \text{ 1/}\Omega\text{ cm}$$

and finally:

$$R = \frac{2}{0.35 \times 10^{-3} \times 2} = 284\ \Omega$$

Sheet Resistance

In integrated circuits, resistors are often fabricated as thin sheets of extrinsic semiconductor material. Supposing the sheet has uniform thickness δ and width w, as shown in Fig. 4.2.7*a*; then its resistance is

$$R = \frac{L}{\sigma w \delta}\ \Omega \tag{4.2.12}$$

If the resistor is square in shape, as in Fig. 4.2.7*b*, then $L = w$ and (4.2.12) becomes

$$R_{\square} = \frac{1}{\sigma \delta}\ \Omega_{\square} \tag{4.2.13}$$

Notice that, for a given material and thickness, all square sheets have the same resistance, independently of the size of the square, provided only they have a square shape. The resistance of such square wafers, indicated as $R_{\square}$ in (4.2.13), is known as the sheet resistance and is measured in ohms per square ($\Omega_{\square}$); it depends only on the thickness of the sheet and its average conductivity.

For the integrated circuit of Fig. 4.2.7*c*, the resistance can then be computed by counting the number of squares in the strip and multiplying by the sheet resistance. Conversely, this method can be used to design the resistor.

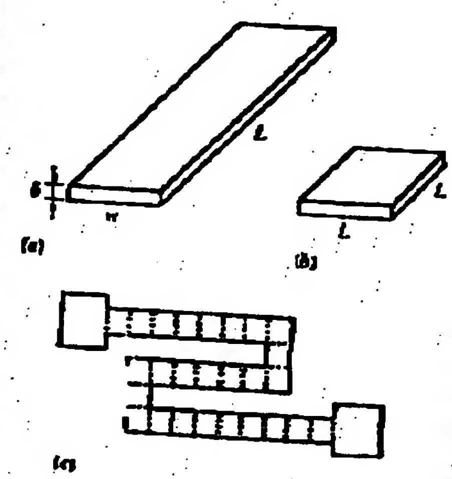

FIGURE 4.2.7
Sheet resistance. (*a*) Sheet resistor of uniform doping, width w, and thickness δ. (*b*) Square sheet resistor of side L. (*c*) Typical integrated circuit sheet resistor. A division into squares to ease computation of the total resistance is indicated by the dotted lines.

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